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THE EFFECTS OF MULTIPLE HEAT TREATMENT ON MAGNETIC HYSTERESIS AND  
SENSITIVITY PROPERTIES OF KAPSTAR (4% NICKEL) STEEL TRANSDUCERS

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In many applications where a standard sensory torque transducer ring would be impractical, two distinct portions of a hollow ferromagnetic high-speed steel shaft can be utilized as a torque transducer, in which a high degree of oppositely polarized circumferential magnetic domain alignment can be maintained, provided the steel has high coercive forces and is not too brittle to withstand the applied torque. In this work, the sample considered was Kapstar high-speed tool steel, whose 4% nickel content allowed it to provide these sufficient coercive forces. This material is also ideal for most industrial tool applications, where such in-situ torque measurements would need to be made, due to its uniform hardness through both thick and thin cross-sections. Additionally, its clean structure, offering consistent textured properties, prevents it from being too brittle for the desired applications. We have discovered that a significant enhancement in transducer sensitivity can be gained by a repeated application of the original heat treatment (five hours at 549°C and slow-cooled at 15°C/hour), with an intervening water quench from 1000°C, without the sacrifice of any essential mechanical properties. Transducer sensitivity was found to increase from 8.18 to 9.35 mG/N-m after the first application of the heat treatment, and then to further increase to 11.17 mG/N-m after its second application. These correspond to field signal versus applied shear stress sensitivities of 0.06256, 0.07152, and 0.0855 mG/psi, respectively. Its linearity over the normal response range needed for such an industrial magnetic transducer also lies within needed tolerances. Corresponding to this sensitivity enhancement, we also found that the area of the axial hysteresis curve slightly decreased following the second heat treatment; these two effects are usually observed to be correlated in our torque transducer studies. However, relatively little change was observed in the already broad circumferential hysteresis curves over the multiple heat treatments, which assures that transducer integrity can be easily maintained throughout this process.